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SURFACE RUN-OFF AND EROSION ON GRANITIC MOUNTAIN SOILS OF IDAHO AS INFLUENCED BY RANGE COVER, SOIL DISTURBANCE, SLOPE, AND PRECIPITATION INTENSITY

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INTRODUCTION

In many parts of the West, the agricultural, industrial, and social enterprises of large communities are entirely dependent upon the resources of adjacent high mountain watersheds, covered normally with grasses, trees, shrubs, and herbaceous vegetation. In the Intermountain forest region, embracing southern Idaho, Nevada, Utah, and southwestern Wyoming, such watersheds, in addition to furnishing the major supply of water for domestic and commercial use and irrigation, support the forage plants that are highly essential to an important livestock industry. In recent years, owing in large measure to the deterioration of the native plant cover by overgrazing, fire, drought, and other causes, accelerated run-off and soil erosion have become a serious problem on many of these watersheds, to the detriment of both range users and water users. Following torrential summer storms especially, surface run-off frequently has been sufficiently rapid and extensive not only to wash productive topsoil from the sloping range lands but also to create floods that rip the stream channels to bedrock and deposit silt and debris in expensive reservoirs and on developed farms and community property, causing tremendous financial losses and economic distress (*15*).[1]

The control of this destructive process and the restoration and preservation of conditions on deteriorated watersheds which will be conducive to silt-free stream flow and maximum forage production on

[1] Italic numbers in parentheses refer to Literature Cited, p. 20.

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the range form a major problem in the West. One important consideration in this connection is the institution of control measures at the point where they may be most effective. It is increasingly clear to those who have sought for more than two decades to solve this problem that the economical point of attack in flood and erosion control is upstream, where the raindrops fall and melted snow begins to seek water level. Here most of the precipitation may either run off the surface, taking valuable soil with it, or percolate through the soil mantle to underground passages for slow delivery to the stream channels as clear water. It is at this stage that, under normal conditions of well-vegetated slopes and benches, a delicate balance is maintained between surficial and subsurface run-off.

The extreme delicacy of this balance is a point often overlooked. Gradients mainly are steep on these watersheds and summer storms torrential, but the grasses, shrubs, and other range plants that have found a foothold not only maintain themselves in the face of these destructive forces, but hold the soil in place as well. The watershed under such conditions has an appearance of stability and impregnable utility. However, all the natural forces of destruction—drought, torrential storms, steep gradients, deep snows, sudden thaws, heat, and cold—are still at work. There is no doing away with them or modifying their violence. When the balance normally maintained by the vegetation is upset by fire or overgrazing, aggravated by drought, not one but many forces are unleashed, to create far-reaching havoc and ruin.

Users of the mountain range have almost uniformly failed to perceive or realize the importance of this balance between surface run-off and seepage. Unconscious of potential disaster, they have built their homes and tilled their farms in the very path of the floods which only the vegetation on the watershed restrained. They have seen that vegetation burned over or grazed to the ground without a suspicion of the inevitable consequences. Now that these consequences have come and often at great cost, the necessity for restoring the natural balance, where this is still possible, is being more widely recognized. The first question is, how this may be accomplished quickly and effectively. Certainly it cannot be done at any other point on the watershed than at the place where the balance was originally maintained and later destroyed. On watersheds where hazards are great and dependent values are high, contour trenches and other engineering works as a supplement to revegetation may be effective and feasible in getting water into the ground (*2*), but most watershed areas needing control are generally far too extensive to permit the expense of mechanical devices. The use of plant cover as a control agent, therefore, deserves special attention, both because range plants can usually be reestablished on these lands naturally or artificially, and because they are known to aid percolation of water into the soil (*10*) and to minimize run-off and erosion (*6*).

Watersheds needing rehabilitation in the West vary widely, however, with respect to their climatic soil and physiographic characteristics and also in the degree to which their soils are subject to disturbance by grazing. Revegetational projects therefore involve the determination of what plants will be most efficient in restraining surface run-off and erosion under the highly variable conditions of precipitation, slope, and soil that prevail on the ranges of this region.

The control problem on the Boise River watershed in southwestern Idaho is similar with respect to its seriousness, the factors contributing thereto, and the measures needed (*11*), to situations prevailing on many other western range watersheds. Until recently this 1,700,000-acre mountainous area not only furnished ample irrigation water for intensive agriculture on nearly 350,000 acres of fertile land in Boise Valley, but also provided summer range for more than 4,000 cattle and 150,000 sheep. In recent years, however, wastage of abnormally early spring run-off which came too early to be used and at a time when water could not be saved because of limited storage space—together with precipitation deficiencies and lost storage space in Arrowrock Reservoir due to silting—have resulted in water shortages severe enough in the poorest years to cause crop losses in excess of a million dollars. Moreover, owing to the replacement of the most valuable forage plants by less palatable species, the grazing capacity of the range has been so lowered that the number of cattle have had to be reduced by at least 25 percent and the number of sheep by 50 percent, adversely curtailing the range livestock industry.

Research by the Forest Service on this important watershed has revealed that, whereas several uncontrollable factors such as steep slopes, a highly erosive granitic soil, and torrential summer storms have had an important bearing on accelerated run-off and erosion, the major cause of this destructive process has been the destruction, disturbance, and modification of the plant cover and surface soil by such controllable agents as placer mining, fire, logging operations, and overgrazing. Placer operations in the canyon bottoms of tributaries to Moores Creek have contributed considerable quantities of silt to Boise River below Arrowrock Dam; and fire and logging operations in the Moores Creek drainage, as well as on limited areas in the headwaters of other major tributaries, have contributed additional quantities. Primary interest, however, has necessarily been focused on what is going on at the lower and middle elevations of the watershed, directly tributary to Arrowrock Reservoir, where accelerated run-off and erosion on severly deteriorated range lands are creating extensive damage.

During 1934 and 1935, four of the important herbaceous range cover types on this portion of the watershed were selected for study and their relative effectiveness in controlling run-off and erosion under conditions of soil disturbance, slope, and rainfall intensity was determined. To overcome the difficulty of making such tests under natural conditions of precipitation, a specially designed rain-making apparatus was employed. This report presents an analysis of the data collected. The studies were designed to yield information concerning this particular problem area, but the results and principles brought out, as well as the experimental technique employed, should be of value in coping with similar range-watershed problems elsewhere.

THE ISOLATION OF VARIABLES

THE RANGE TYPES

The four range types selected for study were wheatgrass, downy chess, lupine-needlegrass, and annual weed. Of these, the wheatgrass type is representative of the grassland climax of the region, being characterized by the dominant fibrous-rooted beardless wheatgrass

(*Agropyron inerme*) and a few comparatively succulent perennial weeds including lupine (*Lupinus comatus*) and arrowleaf balsamroot (*Balsamorhiza sagittata*). This type originally occurred on much of the untimbered portions of the watershed, especially at the lower and middle elevations, the plants usually occupying approximately 35 percent of the surface soil. Bunch-grass stands of this density are found today, however, only on a few small tracts that have been protected from excessive grazing.

The lupine-needlegrass type is characterized, as the name implies, by a mixture of lupine and Letterman needlegrass (*Stipa lettermani*), and is representative of an early stage of range deterioration at the high elevations of the watersheds. In this type, plants normally cover 25 percent of the ground surface. The needlegrass, a short-lived perennial, is distinctly bunch-forming in its growth habit; in height growth and extensiveness of its root system it stands between wheatgrass and downy chess. The lupine is distinguished by abundant foliage and an exceptionally deep taproot with lateral branches at the lower extremities.

Almost pure stands of the annual grass, downy chess (*Bromus tectorum*), commonly known in the West as "cheatgrass," characterize the downy chess type, one of the most common herbaceous types on overgrazed portions of this range. This exotic has been an extensive invader of the range at the lower elevations, following the destruction of the original perennial bunch grasses. The individual plants, while bunch-forming in growth habit, are much smaller than the perennial wheatgrasses they replaced and normally produce a ground cover of only 5 to 20 percent density.

The annual weed type is representative of the plant cover on the most seriously deteriorated ranges of this watershed. These are typified generally by such annual taprooted plants as kitchenweed (*Gayophytum diffusum*), tarweed (*Madia glomerata*), and prickly lettuce (*Lactuca scariola*); and on some areas a few plants of downy chess are found in association with these species. Normally the density of the plant cover on this type of range rarely exceeds 5 percent.

In order to determine the relative effectiveness of each of these types of range for controlling run-off and erosion, it was essential to give consideration to soil texture and several other contributing factors which are operative in common on these areas, including: (1) Trampling of the surface soil, inevitable during grazing; (2) slope steepness, which has a bearing not only on run-off but also on the degree of range utilization; and (3) the amount and intensity of the summer precipitation that falls on these areas.

SOIL

Every effort was made to select study areas having closely comparable soils. The scarcity of wheatgrass areas, the restriction of lupine-needlegrass type to the higher elevations, and the lack of water for operation somewhat limited the choice of test plots, and as a consequence it was necessary to use wheatgrass areas on which the soil contained somewhat less fine material and organic matter than is generally characteristic of that type. However, all of the range types studied occur on a coarse-grained, granitic soil. As summarized in table 1, it can be noted that the soils contain from 77 to 92 percent of gravel and

sand, usually less than 20 percent of silt and clay, and seldom more than 3 percent of organic matter. Although it is recognized that soil texture and composition affect rates of water percolation and extent of erosion, studies of the root systems of plants, absorption studies, erosion surveys, and experience with handling livestock on the Boise granitic soils indicate that the deterioration in the vegetative cover is a far greater factor in influencing run-off and erosion than the differences in soil texture. Studies designed to isolate the soil factors are under way and will be reported in other publications.

SOIL TREATMENT

Observations show the soil to be highly susceptible to disturbance by the trampling of livestock while grazing. Accordingly, in addition to measuring the effectiveness of each range type for controlling run-off and erosion under conditions of undisturbed soil, it was considered essential to include in this study, as a basis for determining grazing practices, measurements on areas where the surface soil had been thoroughly disturbed.

TABLE 1.—*Comparison of 0- to 6-inch samples of soils tested with the portable rainmaking apparatus, and other soils in the same vegetative types*

Types and areas sampled	Soil fractions					Organic matter in total sample
	Coarse gravel (>5 mm)	Fine gravel (5–2 mm)	Sand (2–0.05 mm)	Silt (0.05–0.005 mm)	Clay (<0.005 mm)	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Wheatgrass type:						
Tested areas	24	38	30	6	2	0.8
Other areas	19	25	40	12	4	1.7
Downy chess:						
Tested areas	14	30	41	11	4	.7
Other areas	17	20	42	13	8	.9
Lupine-needlegrass type:						
Tested areas	7	16	60	12	5	3.0
Other areas	11	16	51	15	7	3.2
Annual weed type:						
Tested areas	14	24	39	16	7	.9
Other areas	15	27	38	13	7	1.0

STEEPNESS OF SLOPE

Another major characteristic of these range types is steep slope. A detailed survey on 371,000 acres of the range portion of the watershed revealed the average slope to be approximately 45 percent. Renner (*11*) observed that erosion appeared to increase with increase in slope up to 35 percent but that on steeper areas there was no further increase. He attributed this phenomenon to the heavier grazing and greater disturbance of the soil on the lower than on the steeper slopes. In order to clarify this relationship, and to establish a basis for determining the relative hazards of permitting soil disturbance on steep slopes, areas within each type were selected for study that were characterized by 40-percent as well as 30-percent slopes.

PRECIPITATION INTENSITY

While the Boise River watershed as a whole is recognized as being in a region of relatively low precipitation (*16*), the higher range portion is known to receive from 25 to 50 inches or more each year, of which as

much as 2 inches may fall as rain in a single storm during the summer months. Many of the summer storms on this area are characterized by a low rate or intensity of fall, but there is usually at least one storm each year of moderate intensity—at the rate of 0.03 inch per minute—and comparatively recent records indicate that occasional heavy storms may reach 0.10 inch per minute for brief periods and 0.06 inch per minute for longer periods (table 2). These are the storms directly responsible for the occurrence of excessive run-off and erosion. Because of their occurrence it was necessary to obtain run-off and erosion records from each of the four range types under conditions of moderate as well as high rainstorm intensities. On the basis of available records and in consideration of the apparatus used, it was considered that storms of 1.80 inches falling in periods of 60 minutes (0.03 inch per minute) and of 30 minutes (0.06 inch per minute) would indicate the efficiency of these areas under the conditions of moderate and high rainfall intensities expected.

TABLE 2.—*Maximum rainfall rates recorded at mountain stations, 1936–37* [1]

Station	5 minutes	10 minutes	15 minutes	20 minutes	25 minutes	30 minutes	60 minutes
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Bannock Creek, Idaho (5,300 feet)	0.50	0.74	0.88	1.01	1.10	1.18	
Parrish Creek, Utah (8,350 feet)			.95				
Miller Canyon, Utah (6,800 feet)	.26	.50	.64				

[1] The period of record from the Utah stations was June 1, 1936, to Jan. 1, 1937; at the Idaho station the record began July 1, 1936.

HOW RUN-OFF AND EROSION WERE MEASURED

Combinations of these different phases of the four variables studied—the four range types, undisturbed and disturbed surface soil, 30- and 40-percent slopes, and moderate- and high-intensity rainfall—involved 32 experimental conditions. These were replicated three times, making a total of 96 areas on which run-off and erosion were measured. Little difficulty was encountered in locating suitable study areas within each of the range types, but in order to obtain results at minimum cost of time and cash outlay for instrumentation, special apparatus was developed for producing artificial rainstorms of the desired amount and intensity and for measuring the resulting run-off and erosion (fig. 1).

The major parts of this apparatus included a pump unit for supplying water under pressure from the nearest creek or lake or from a portable storage tank; a sprinkler system capable of producing artificial storms over areas approximately 15 by 50 feet; sheet-metal equipment for delimiting a plot 6.6 by 33 feet (0.005 acre) and for collecting run-off and eroded material; devices for measuring and recording the amount and rate of rainfall and run-off; and miscellaneous equipment for sampling the soil and the run-off that passed through the tipping bucket run-off gage, and for preparing eroded soil for weighing and analysis.[2]

This apparatus combines the artificial-rainfall features of the instrumentation used by Lowdermilk (*7*) and Duley and Ackerman (*4*) with field-plot methods used by Lowdermilk (*8*), Meginnis (*9*), and

[2] For a more detailed description of this apparatus see Appendix.

many other workers, but differs from all these in that it is completely portable.

With the aid of this apparatus, measurements of run-off and erosion were made on the 96 1/200-acre test plots in accordance with a standard procedure. Study areas having slopes between 29 and 31 percent and 39 and 41 percent, respectively, were located within each of the four range types. The composition and density of the plant cover on each area was cataloged and 6-inch soil samples were taken for mechanical and chemical analysis. Prior to the application of rainfall on each test plot, samples were taken of the surface one-half inch of soil for mechanical and chemical analysis and comparison

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FIGURE 1.—The portable erosion-study apparatus, or "rain maker," in operation in the downy chess range type.

with similar samples taken after the induced storm and with samples of the eroded material. Tests were made only when the surface soil moisture content was less than 5 percent.

On one-half the number of plots on each slope, rainfall was applied without disturbing the soil except for the minor disturbance that was unavoidable in placing the baffle plates and collector trough. On the other plots, the surface inch of soil was scuffled by the operators prior to making the test, to simulate the disturbance caused by the trampling of livestock.

Between 1.75 and 1.85 inches of precipitation was applied in 60 minutes to simulate a moderately intense storm on one-half the plots and in 30 minutes to approximate high intensity rainfall on the others. The volume of run-off was measured and tabulated as a percent of the rainfall applied. Eroded material was collected, air-dried, weighed,

and tabulated in terms of tons per acre. Mechanical analysis of the soil was made by the Bouyoucos method (*3*). Nitrogen was determined in accordance with the official Kjeldahl method as modified by Gunning (*1*). The Schollenberger method (*12*) was used for obtaining the organic-matter content.

EXPERIMENTAL RESULTS

The percent of artificial rainfall which ran off the surface of the ground and the tons per acre of material eroded varied greatly among the 32 experimental conditions (table 3 and fig. 2). The general type means indicate the relative value of the three inferior types for control-

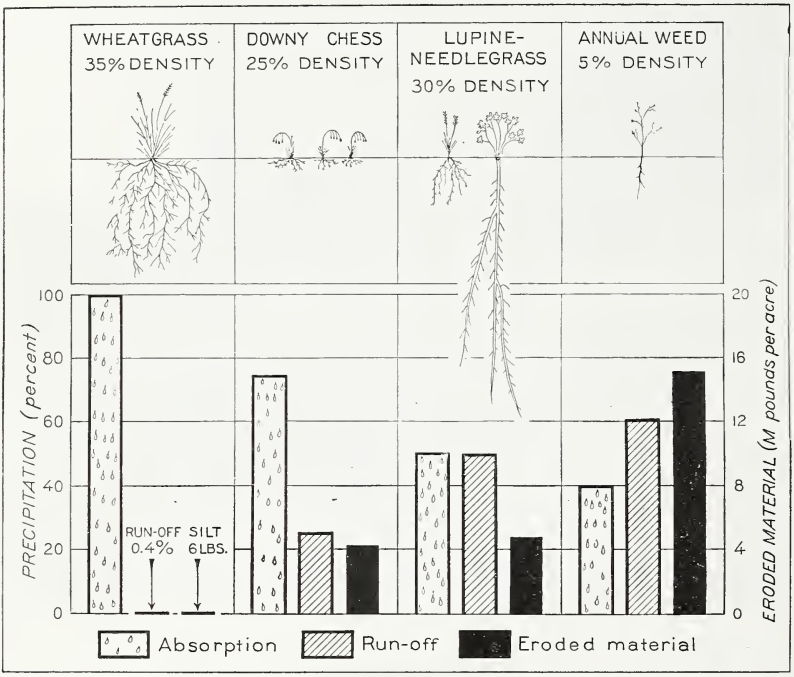

FIGURE 2.—Diagrammatic comparison of the utility of the four range cover types in facilitating infiltration of storm waters and so reducing run-off and accelerated erosion.

ling run-off and erosion under the conditions of this experiment. The superiority of the wheatgrass range type in watershed protection is clearly shown in that run-off from this type amounted to less than 0.5 percent and the soil eroded to only 0.003 ton per acre. The downy chess type is only moderately effective as a protective cover, and the lupine-needlegrass type is of little value. The annual weed type, permitting a run-off of 60.8 percent and erosion of 7.64 tons per acre, can be regarded only as an erosion hazard. On all three types combined, increase in rainfall rate increased run-off one-third and erosion two-thirds, while the steepest slopes in general yielded one-fifth more run-off than the more gentle slopes but nearly 3½ times the eroded material. Soil disturbance resulted in a very slight increase in run-off, but erosion from disturbed soil was 1.7 times as great as from natural soil.

TABLE 3.—*Run-off and erosion results under each of eight experimental conditions on the four vegetation areas* [1]

RUN-OFF PERCENT OF APPLIED RAINFALL

Slope, intensity of rainfall, and soil treatment	Wheatgrass	Downy chess	Lupine-needlegrass	Annual weed	Average of types
30-percent slope:					
Moderate-intensity rainfall:					
Undisturbed soil	0.7	9.8	43.5	46.1	33.1
Disturbed soil	.2	4.9	54.9	62.0	40.6
High-intensity rainfall:					
Undisturbed soil	.8	4.7	56.5	53.9	38.4
Disturbed soil	.4	29.4	67.3	61.9	52.9
40-percent slope:					
Moderate-intensity rainfall:					
Undisturbed soil	.3	25.6	44.1	60.9	43.5
Disturbed soil	.2	25.6	24.1	59.7	36.5
High-intensity rainfall:					
Undisturbed soil	.2	53.3	54.7	71.8	59.9
Disturbed soil	.3	50.4	54.2	69.8	58.1
30-percent slope, mean	.7	12.2	55.55	55.98	41.24
40-percent slope, mean	.3	38.72	44.28	65.55	49.52
Moderate-intensity rainfall, mean	.5	16.48	41.65	57.18	38.43
High-intensity rainfall, mean	.6	34.45	58.18	64.35	52.32
Undisturbed soil, mean	.7	23.35	49.70	58.18	43.74
Disturbed soil, mean	.4	27.58	50.12	63.35	47.02
General mean	.4	25.5	49.9	60.8	45.4

TONS PER ACRE OF ERODED MATERIAL

30-percent slope:					
Moderate-intensity rainfall:					
Undisturbed soil	0.003	0.14	1.22	0.84	0.73
Disturbed soil	.003	.08	1.77	2.02	1.29
High-intensity rainfall:					
Undisturbed soil	.003	.05	2.28	2.79	1.71
Disturbed soil	.003	.86	4.05	3.93	2.95
40-percent slope:					
Moderate-intensity rainfall:					
Undisturbed soil	.003	.22	1.13	12.23	4.53
Disturbed soil	.003	.72	1.80	10.86	4.46
High-intensity rainfall:					
Undisturbed soil	.003	1.48	2.09	8.16	3.91
Disturbed soil	.003	4.86	4.73	20.29	9.96
30-percent slope, mean	.003	.28	2.33	2.40	1.67
40-percent slope, mean	.003	1.82	2.44	12.88	5.71
Moderate-intensity rainfall, mean	.003	.29	1.48	6.49	2.75
High-intensity rainfall, mean	.003	1.81	3.29	8.79	4.63
Undisturbed soil, mean	.003	.47	1.68	6.00	2.72
Disturbed soil, mean	.003	1.63	3.09	9.28	4.66
General mean	.003	1.05	2.38	7.64	3.69

[1] The values shown are each the mean of 3 replicate tests.

The relative importance of the four variables of the study in influencing surface run-off and erosion was determined by means of variance analysis, the results of which are summarized in table 4.[3] [4] This analysis shows that surface run-off was affected mostly by range type, since the variance associated with this factor is more than twice that of the next most important factor, rainfall intensity. Steepness of slope is third in importance. Soil disturbance, with a variance five times the experimental error, has a small but probably significant effect upon run-off. Erosion was affected mostly and about equally by vegetative type and steepness of slope and to a lesser, though significant degree, by soil disturbance and rainfall intensity.

[3] The wheatgrass type, which yielded an insignificant amount of run-off or eroded material, was not included in this analysis.

[4] For discussions of the use and interpretation of the method of variance see Fisher (*5*) and Snedecor (*13*).

TABLE 4.—*Summary of variance analysis* [1]

RUN-OFF PERCENT OF APPLIED RAINFALL

Variance due to—	Sum of squares	Degrees of freedom	Mean square
Vegetative type	15,709.22	2	**7,854.61**
Rainfall intensity	3,476.39	1	**3,476.39**
Steepness of slope	1,235.87	1	**1,235.87**
Soil treatment	192.41	1	*192.41*
Interactions	7,516.20	18	417.57
Error	1,862.73	48	38.81
Total	29,992.82	71	

TONS PER ACRE OF ERODED MATERIAL

Vegetative type	581.70	2	**290.85**
Rainfall intensity	63.36	1	**63.36**
Steepness of slope	294.09	1	**294.09**
Soil treatment	68.16	1	**68.16**
Interactions	584.46	18	32.47
Error	412.29	48	8.59
Total	2,004.06	71	

[1] Quantities in italics are of probable significance when compared to error; those in boldface are highly significant.

The significant value of the variance ascribed to "interactions" in both parts of table 4 indicates that the four variables did not influence run-off and erosion to the same degree under all conditions of the experiment. Thus, increase in slope had more effect upon run-off in one vegetative type than in another. In order to investigate these interactions, separate analyses of variance have been made for each of the three types shown in table 5.[5]

TABLE 5.—*Summary of variance analyses by vegetation types* [1]

RUN-OFF PERCENT OF APPLIED RAINFALL

Variation due to—	Degrees of freedom	Downy chess	Lupine-needlegrass	Annual
Rainfall intensity	1	**1,942.20**	**1,640.11**	**308.16**
Steepness of slope	1	**4,226.76**	**763.88**	**552.96**
Soil treatment	1	105.42	1.22	*160.16*
Rainfall × slope	1	*412.51*	89.71	67.34
Rainfall × soil	1	*267.34*	134.42	27.74
Slope × soil	1	193.24	**684.80**	*276.08*
Higher order interaction	1	*396.08*	*152.01*	18.73
Error	16	49.47	32.51	34.44
Total	23	8,335.06	3,986.26	1,962.28

TONS PER ACRE OF ERODED MATERIAL

Rainfall intensity	1	**13.89**	**19.55**	31.79
Steepness of slope	1	**14.19**	.07	**659.21**
Soil treatment	1	**8.08**	*11.86*	64.20
Rainfall × slope	1	**8.28**	.12	.84
Rainfall × soil	1	**5.30**	3.80	67.93
Slope × soil	1	**3.67**	.36	26.65
Higher order interaction	1	1.52	.21	68.54
Error	16	.43	1.56	23.77
Total	23	61.88	60.94	1,299.53

[1] Quantities in italics are of probable significance when compared to error; those in boldface are highly significant.

[5] Owing to the comparatively great variation in the values in tables 3 and 4, it was not deemed advisable to base the discussion of interaction of variables on the variance analysis for the data as a whole. Since the variance ascribed to error is weighted by each of the values included in this analysis, it is too large to serve as a basis for comparing factors which have produced low values of run-off and erosion, such as in the cheatgrass type; and it is deceptively small when used as a test of significance between high run-off or erosion values, as in the annual weed type. The use of separate variance analyses for each type overcomes this objection.

THE WHEATGRASS RANGE

The superiority of the wheatgrass range cover for controlling run-off and erosion is the most striking result of this study (fig. 3). This type of range yielded practically no run-off or eroded material, as compared to an average run-off of 45.4 percent and 3.69 tons per acre of eroded material on the other three range types studied. Moreover, the

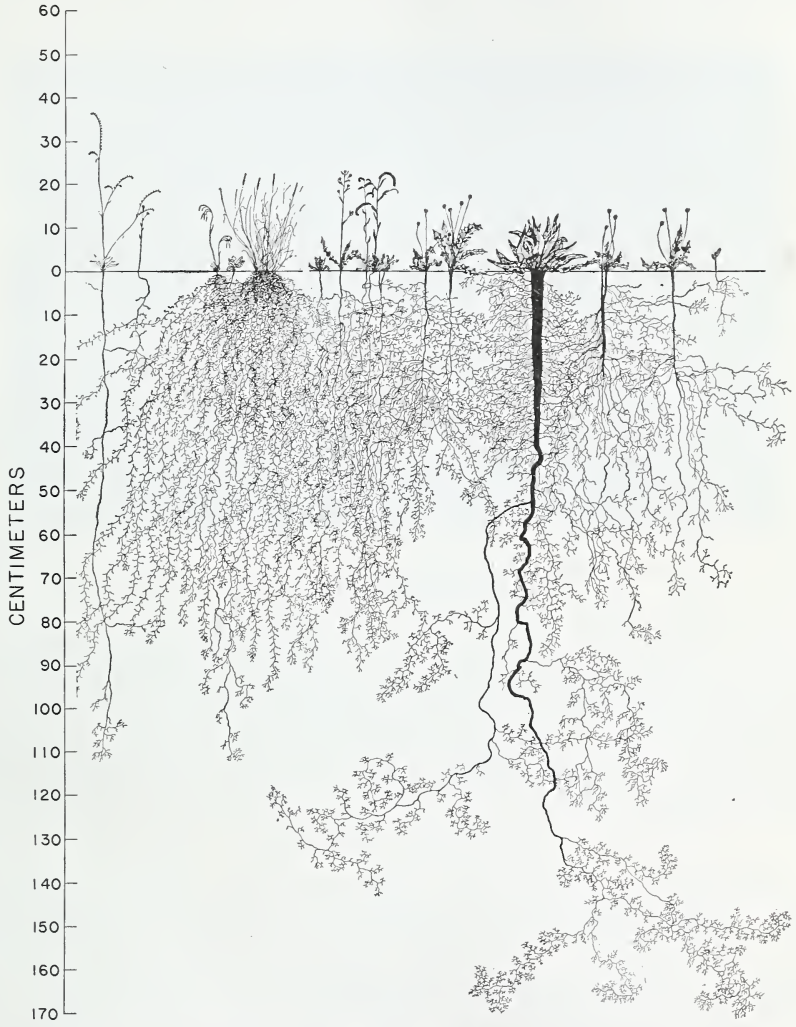

FIGURE 3.—Transect of wheatgrass, showing the dense mass of fibrous roots that hold the soil and aid water infiltration.

wheatgrass cover was equally effective under all conditions; on 40-percent as well as on 30-percent slopes, when subjected to either high or moderately heavy rainfall intensities, and when the soil was thoroughly disturbed to simulate trampling by grazing animals or left undisturbed.

The results of these tests substantiate the conclusion of Renner (*11*), based on numerous observations and surveys made over the watershed, that the wheatgrass type is highly effective in preventing erosion. (Fig. 4.) It is widely recognized that stands of wheatgrass which have not been deteriorated by overgrazing seldom show signs of accelerated erosion even on steep slopes. The effectiveness of the wheatgrass type, it is believed, is due largely to the extensive fibrous root system developed by most of the species in the type, as pointed

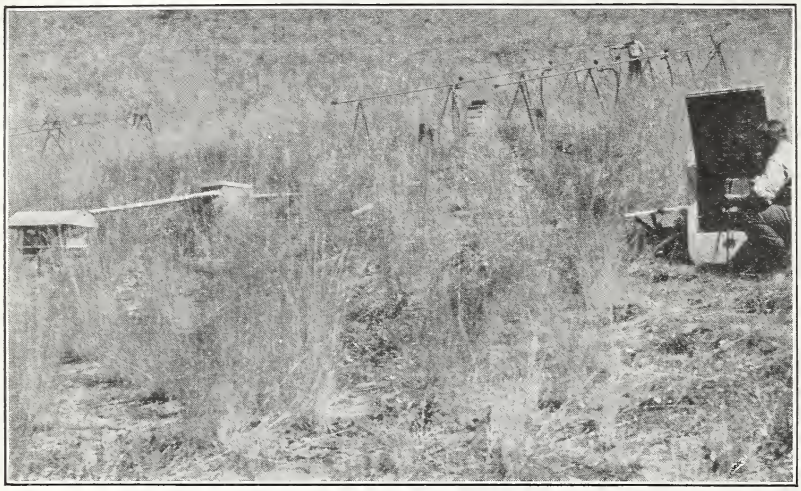

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FIGURE 4.—Tests on wheatgrass range with the rain maker have proved the value of this type of cover under all natural conditions of range use.

out by Spence (*14*). Cross sections through such plant communities reveal a heavy and continuous mass of fibrous roots which effectively binds the soil in place and promotes the absorption of much surface water. Studies by Pearse and Woolley (*10*) of the rate of absorption of surface water by soils indicate that fibrous-rooted plants, of which wheatgrass is a typical example, are about two and one-half times as effective in promoting absorption of surface water by soils as are tap-rooted species.

THE DOWNY CHESS RANGE

Although much less effective than wheatgrass, downy chess range (fig. 1) which yielded on the average only 25.5-percent run-off and 1.05 tons of eroded soil per acre, was about twice as effective for controlling run-off as lupine-needlegrass and annual weed cover types, and from two to seven times more efficient in preventing erosion.

Steepness of slope was the most important variable influencing run-off and erosion in the downy chess type (table 5). Three times as much run-off and six and one-half times as much erosion were yielded from the 40-percent as from the 30-percent slopes (table 3). On the gentler slopes, run-off amounted to only 12 percent of the

applied rainfall and erosion to only 0.28 ton per acre as compared with 39-percent run-off and 1.82 tons of erosion from the 40-percent slopes. Sheet erosion without the formation of gullies occurred on the 30-percent plots, while on all of the 40-percent plots a number of shoestring gullies developed as a result of the storm.

The increase in slope, however, was not equally effective under all conditions of the experiment, as shown by the significant interactions involving slope in table 5. It has more effect on both run-off and erosion under high than under moderate intensities of rainfall (table 6). Under the moderate-rainfall intensities the steeper slopes yielded only 18.2 percent more run-off and 0.36 more tons of eroded material per acre than did the more gentle slopes, as compared to increases of 34.8 percent in run-off and 2.71 tons of eroded matter under the high intensities of rainfall.

TABLE 6.—*Interaction of variables on downy chess type*

Interacting variables	Slope		Soil	
	30 percent	40 percent	Undisturbed	Disturbed
RUN-OFF PERCENT OF APPLIED RAINFALL [1]				
Rainfall intensity, moderate	7.4	25.6	17.7	15.2
Rainfall intensity, high	17.0	51.8	29.0	39.9
TONS PER ACRE OF ERODED MATERIAL [2]				
Rainfall intensity, moderate	0.11	0.47	0.18	0.40
Rainfall intensity, high	.46	3.17	.76	2.86
Slope, 30 percent			.10	.47
Slope, 40 percent			.85	2.79

[1] Significant difference (5 percent) 8.6.
[2] Significant difference (5 percent) 0.806.

As shown by the nonsignificant interaction in table 5, soil disturbance did not affect the influence of slope upon run-off, but the variance analysis shows that erosion was more affected by increase in slope on the disturbed than on the undisturbed soils. As a result of increase in steepness of slope, erosion increased only 0.75 ton per acre on the undisturbed soils as compared to an increase of 2.32 tons per acre on the disturbed soils.

Rainfall intensity was the second most important factor in the downy chess type (table 5). As a result of increase in rainfall from moderate to high intensity, run-off was increased by 18 percent and erosion was increased by more than 1.5 tons per acre (table 3).

The significant interactions involving rainfall intensity in the variance analyses indicate that this effect of rainfall intensity is not the same under all conditions of the experiment (table 5). Increase in rainfall rate increased the percent run-off by 9.6 on the 30-percent slopes (table 6) and by 26.2 on the 40-percent slopes. Erosion was similarly increased only 0.35 ton per acre on the 30-percent slopes as compared to 2.70 tons per acre on the 40-percent slopes.

Increased rainfall intensity was also much more destructive on disturbed than on undisturbed soils. On the undisturbed soils run-off increased 11.3 percent and erosion 0.58 ton per acre as a result of

increase in precipitation rate, while on the disturbed soils run-off increased 24.7 percent and erosion 2.46 tons per acre when the rainfall rate was increased.

Although disturbances of the surface soil had no significant effect upon run-off in the downy chess type, it had considerable influence on erosion, expressed in a highly significant increase from 0.47 to 0.63 tons per acre as a result of soil disturbance (table 3).

Soil disturbance resulted in no significant change in run-off from either the 30- or 40-percent slopes as indicated by the nonsignificant interaction in the first part of table 5. Erosion, however, was increased by 0.37 ton per acre as a result of soil disturbance on 30-percent slopes (table 6) as compared to an increase of 1.94 tons per acre on the 40-percent slopes.

Both run-off and erosion were more influenced by soil disturbance under high than under moderate rainfall intensities in the downy chess type. Neither showed any significant change as a result of soil disturbances on the moderate-intensity-precipitation plots, but under high-intensity rainfall disturbed soils yielded 10.9 percent more run-off, and erosion was increased by 2.1 tons per acre.

In short, the downy chess type is moderately effective in controlling run-off and erosion, especially under the less rigorous conditions. The 30-percent slopes in general were rather well protected in the downy chess type, and even the 40-percent slopes were fairly stable under moderately heavy storms. Storms of 0.03 inch per minute did not produce an alarmingly high rate of run-off or erosion, and even the higher precipitation intensity was comparatively ineffectual except on the steeper slopes. Soil disturbance had little effect on run-off but greatly increased erosion especially on the steeper slopes and under the higher intensities of rainfall. The root system of downy chess is fibrous but not extensive. These characteristics, it appears, are effective in promoting absorption and percolation of water into the soil under conditions of moderately intense rainfall, but are markedly deficient for inducing percolation or for holding the surface soil in place during storms of high intensity.

THE LUPINE-NEEDLEGRASS RANGE

On the average, 49.9 percent of the applied rainfall and 2.38 tons of soil per acre were yielded from the lupine-needlegrass range (fig. 5), or about twice as much as from the downy chess range (table 3 and fig. 5). While run-off and erosion were in general so much greater, and all of the plots were gullied as a result of the storm, the inefficiency of this type of cover was especially noticeable under certain conditions of the experiment.

Increase in slope, while not the most important factor, had an anomalous effect on run-off and erosion in the lupine-needlegrass type (table 3). Run-off decreased significantly from 55.6 percent on the 30-percent slopes to 44.3 percent on the 40-percent slopes, while erosion was unchanged. This effect of slope persists under almost all of the combinations of rainfall intensity and soil disturbance, as shown by the nonsignificant interactions in the lupine-needlegrass type in table 5. Only one interaction, that involving slope and soil is significant, affecting run-off only, as follows:

	Run-off, percent
30-percent slope:	
Undisturbed soil	50. 0
Disturbed soil	61. 1
40-percent slope:	
Undisturbed soil	49. 4
Disturbed soil	39. 2

Increase in slope had no evident influence on run-off from undisturbed soils—the general decrease in run-off with increased slope being due to a 21.9-percent decrease on the disturbed soil. The significant difference (5 percent) is here 7.0.

Rainfall intensity was the most important variable in influencing run-off and erosion in the lupine-needlegrass type. Under high-rainfall intensity as compared to moderate intensity, run-off of the applied precipitation increased by 16.5 percent and an additional 1.81 tons per acre of material was eroded.

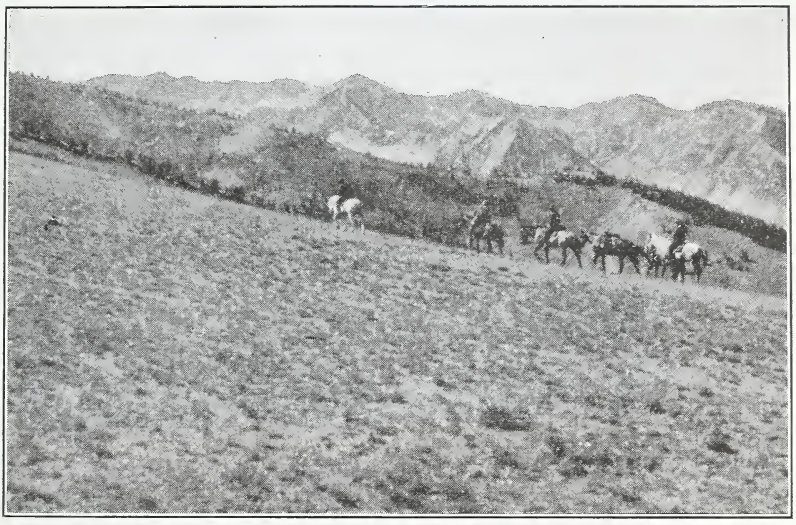

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FIGURE 5.—Lupine-needlegrass, a common range type at the high elevations, is of little value for erosion control.

The effect of rainfall was not significantly modified by other variables in the experiment (table 5), and from this it must be concluded that the increase in run-off and erosion was about the same regardless of the steepness of slope or treatment of the soil.

Run-off from the lupine-needlegrass type in general was not affected by disturbance of the soil, although erosion was nearly doubled—3.09 tons per acre of eroded material as compared to only 1.68 tons from undisturbed soil.

The lack of any general effect of soil disturbance on the amount of run-off is due to the reciprocating effects of soil disturbance on the two slopes—11.1-percent increase on the 30-percent slopes was compensated by a 10.2-percent decrease on the 40-percent slopes. This compensating difference has already been accounted for in connection with the discussion of slope. Soil disturbance affected erosion about equally on the two slopes.

These data show that notwithstanding the special influences of slope, soil disturbance, and rainfall intensity, run-off and erosion are excessive from the lupine-needlegrass type under all of the conditions of the experiment. The type is especially vulnerable to storms of high-rainfall intensity, but even storms of 0.03 inch per minute result in more than 40-percent run-off and an alarming amount of erosion. The ineffectiveness of the type is probably due to the deficiency of fibrous-rooted plants. Lupine, the dominant species, has practically no branch roots in the surface soil, and needlegrass, the only common fibrous-rooted member of the community, is in the minority and has a rather small root system.

THE ANNUAL WEED RANGE

The annual weed type, yielding on the average 60.8-percent run-off and 7.64 tons per acre of eroded material, was obviously the least efficient in watershed protection of the four kinds of range studied (fig. 6). Gully erosion occurred on all plots and more severely than in any of the other types. There was so much variation in run-off and especially in erosion among the replicate plots in this type that effects of variation in rainfall intensity and soil condition are difficult to determine statistically.

Steepness of slope, however, had a highly significant influence on both run-off and erosion, and was the most important of the variables studied in the annual weed type (table 5). Increase of slope from 30 to 40 percent increased an already disastrous run-off by nearly 10 percent and added more than 10 tons an acre to the eroded material, producing the alarming total of nearly 13 tons per acre (table 3).

The effect of slope in increasing run-off varied with the condition of the surface soil, as indicated in table 5 and shown statistically as follows:

	Run-off, percent
30-percent slope:	
Undisturbed soil	50. 0
Disturbed soil	62. 0
40-percent slope:	
Undisturbed soil	66. 4
Disturbed soil	64. 8

Run-off was increased by 16.4 percent on the undisturbed soils by increase in slope, but the heavier run-off from the disturbed soil was not significantly affected by change in slope, the significant difference (5 percent) being 7.2. The increase in erosion, amounting to over 10 tons per acre was not significantly affected by soil disturbance. The effects of slope in increasing both run-off and erosion were not materially changed by the rate of rainfall applied (table 5).

Intensity of rainfall in general was, however, important in influencing run-off in the annual weed type, but not erosion. Under a high rate of rainfall, 7.2 percent more of the precipitation ran off than under the lower.

Since none of the interactions involving rainfall intensity and the other variables have any statistical significance, it is concluded that increase in rate of rainfall increased run-off to the same degree regardless of variation in slope or soil disturbance.

Disturbance of the surface soil caused a probably significant increase of 5.2 percent in run-off from the annual weed range as a whole. Erosion increased considerably as a result of soil disturbance, but be-

cause of the great variation in erosion from the replicate plots no statistical significance can be attached to it.

The significant influence of soil disturbance upon run-off appears on the 30-percent slopes, where the disturbed plots yielded 12 percent more run-off than did the undisturbed plots; on 40-percent slopes there was little difference in the heavy run-off.

Other interactions involving soil treatments are not significant, and it must be concluded, insofar as this experiment goes, that disturbance resulted in a general increase in run-off, most of which occurred on the 30-percent slopes. Soil disturbance had no significant influence on erosion under any conditions in this type.

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FIGURE 6.—The annual weed type erodes seriously even under rainstorms of moderate intensity. A plot on a 40-percent slope is being tested with the portable apparatus.

Under all of the conditions of the experiment, run-off and erosion from the annual weed type was so excessive that the influence of the different variables is of little importance. Even under the best conditions this type is so undesirable that it has no place on any well-managed watershed.

As has been pointed out by Spence (*14*), all of the plants of this range type have simple taproots which are ineffective in promoting absorption or in soil binding. The above-ground portions also are of little value in erosion control since the sparse foliage intercepts but little rainfall and offers the soil but little protection from the direct impact of the rain.

SOIL CHANGES ACCOMPANYING EROSION

In order to study the effect of erosion upon the physical and chemical properties of the soil in the annual weed, downy chess and lupine-needlegrass types, a number of surface half-inch soil samples from the plots before and after the application of the artificial rainstorm, as well as samples of the eroded material, were taken for laboratory analysis (table 7). These indicated that the finer particles were

eroded more readily than were the sand and gravel, resulting in a coarser soil after the rain. There was also a differential erosion of organic matter and total nitrogen as shown by the greater percentage of these fractions in the eroded material than in the original soil. Thus the surface soil lost 6 percent of its silt, 7 percent of its clay, 20 percent of its organic matter and 20 percent of its nitrogen as a result of one storm. The decrease in total nitrogen in the surface soil concomitant with erosion might be partly due to leaching of nitrates to lower depths, but the relatively high nitrogen content of the silt indicates an effective differential erosion which seriously depletes the soil fertility. These significant soil changes as the result of differential erosion from a single storm indicate the manner in which erosion robs the soil of its fertility even faster than the topsoil is removed.

TABLE 7.—*Comparison of mechanical and chemical constituents of the surface half inch of soils before and after rain, and of the eroded material*[1]

Determinations	Mean amount present in—		
	Soil before rain	Soil after rain	Eroded material
Mechanical analysis:	*Percent*	*Percent*	*Percent*
Coarse gravel (>5 mm)	20.0	18.8	**3.7**
Gravel (5–2 mm)	23.7	*27.5*	25.6
Sand (2–0.05 mm)	43.8	42.0	41.0
Silt (0.05–0.005 mm)	8.3	7.8	**20.5**
Clay (<0.005 mm)	4.2	3.9	9.2
Total	100.0	100.0	100.0
Organic matter	3.05	2.44	5.35
Total nitrogen	.147	.117	.229

[1] Quantities in italics are probably significantly different from soil before rain; those in boldface indicate highly significant differences.

SIGNIFICANCE OF THE RESULTS TO WATER AND RANGE USERS

The most obvious conclusion from this study is the unquestionable superiority of the wheatgrass range over other existing range types for controlling run-off and erosion. The evidence obtained thus far indicates that the wheatgrass type can be relied upon to minimize flash run-off and erosion even under conditions of torrential rainstorms and steep slopes. As long as the character of the cover is unaltered and its original density maintained, it can be grazed by livestock and game and its effectiveness in controlling run-off and erosion will not be greatly reduced. In addition to being effective in controlling run-off and erosion, the nutritious grasses of this range type are highly desirable as forage plants. It is clear, therefore, that the aims of stockmen and water users alike will be best served in this locality by providing for the development and maintenance of unbroken stands of wheatgrass such as now occur only on conservatively grazed range—at least until another vegetative cover that will serve as well in watershed protection and forage production is introduced through investigation or experience. Soil surveys on the watershed prior to this study indicate that revegetation of wheatgrass may be a long-time undertaking, however, and one that probably should involve intensive

management. Plant nutrients have been leached from the topsoil to such an extent that it may be necessary on many areas, in addition to controlling carefully the grazing use, to reseed artificially with species more adapted to prevailing soil conditions and make no attempt to bring back the wheatgrass until the fertility of the soil is restored.

Downy chess, as shown by this study, has considerable erosion-control value, especially since it is able to grow on impoverished soil and to act as a first aid until more desirable watershed plants can become established. Further, it is not aggressive and will not compete with higher types of range cover under suitable systems of grazing. This type of range is not without serious limitations however. It may furnish a desirable quantity of forage for a few weeks in the spring of a favorable growth year, but in a bad year may be entirely eliminated from the range. Because of the sharp increase in erosion that followed soil disturbance on the 40-percent slopes, the indication is that downy chess slopes steeper than 30 percent should not be grazed. Moreover, while storms of moderate intensity will seldom cause serious erosion from areas well vegetated by downy chess, the torrential storms normally to be expected in this section will undoubtedly bring about serious damage. For these reasons, and because of its varying density and vigor from year to year owing to fluctuations in weather and susceptibility of the seeds to smut, the replacement of downy chess by perennial fibrous-rooted plants should proceed as rapidly as possible. It is unwise to burn off the downy chess when dry, as is often done, since this again exposes the soil to serious erosion and may delay restoration to a better cover.

In the lupine-needlegrass type, high-intensity rainfall is destructive, and even storms of moderate intensity cause dangerously large amounts of run-off and erosion; hence this range type is highly ineffectual and undesirable for watershed protection. It seems quite possible, however, that the erosion control as well as the grazing value of the type might be measurably increased by applying range-management methods to encourage the development of the needlegrass and other fibrous rooted plants, at the expense of the taprooted lupine. There is little doubt that this can be accomplished by intensive management of the high ranges, to the mutual advantage of stockmen and water users.

Little need be said concerning the place of the annual weed type in range-watershed management. It is of little or no value at best for grazing, and areas supporting it constitute an erosion hazard that requires immediate attention in the interest of protection of forage and soil resources, as well as from the standpoint of providing for usable stream flow. If, because of soil depletion or lack of seed supply on this type of range, vegetative control by the establishment of stands of more effective plants cannot be attained in a reasonably short time, artificial planting should be employed. Soil analyses have indicated that inadequate supplies of nitrogen and phosphorus in most of the soils needing rehabilitation will materially increase the difficulty of obtaining rapid improvement. Accordingly, soil-building species will probably have to be grown on these depleted areas as a nurse crop before reseeding with more desirable range-watershed plants, such as wheatgrass, can be attempted.

In addition to showing the relative effectiveness of four range types for controlling run-off and erosion, this study, in the phase dealing with soil changes, not only indicates how excessive sheet erosion and preferential removal of the more valuable soil constituents can bring about serious depletion of the soil, but also emphasizes the need for the immediate control of this destructive process on areas where the plant cover has been impaired. In other words, not only do deteriorated ranges constitute a flood and erosion hazard but, because each storm takes a large fraction of the fine-textured soil and plant nutrients with it, the difficulty of revegetating such areas is redoubled. How deteriorated range on the Boise River watershed and on comparable areas elsewhere is to be restored, is a serious problem which can be solved only by further intensive research.

The present study shows definitely, however, that efforts in this direction must have as their ultimate objective the restoration of the wheatgrass cover, or one that is equally effective in preventing surface run-off and erosion under the naturally severe topographic and climatic conditions prevailing on western watersheds. It is logical to assume that such a cover, when established, will not only increase the grazing capacity of the range to the benefit of livestock producers, but will also induce percolation of water into the ground where it falls. By minimizing surface run-off and erosion, such a cover will promote deep seepage and silt-free stream flow of maximum usefulness to dependent valley water users.

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APPENDIX

PORTABLE RAIN MAKER AND EROSION-STUDY APPARATUS

In order that the 96 tests required for the study could be completed in minimum time, two complete units of the rain-making and erosion-study apparatus were used. One was designed to produce and measure the effect of artificial storms of 0.03 inch per minute intensity; the other, storms of 0.06 inch per minute. Both were alike, with the exception of the sizes of some of the parts, and will, therefore, be described as a single unit.

The unit consists of the following parts:

1. A pump and hose line for supplying water under pressure to the experimental area.
2. A sprinkler system to apply the water to the plot in the manner of rain.
3. Plot equipment to delimit a 1/200-acre plot and catch the run-off and eroded material.
4. Devices to measure and record the intensity of artificial rainfall, the resulting run-off and the amount of material eroded.
5. A truck and trailer to transport the entire apparatus from one experimental area to another.

A 2-inch rotary-gear pump powered by a suitable gasoline motor is used in conjunction with bilateral rubber-lined fire hose coupled in 50-foot lengths to supply water under pressure. Commercially manufactured portable fire units are highly satisfactory for this purpose, the ones used in this study being capable of supplying water through 1,500 feet of hose with a vertical lift of 350 feet to the experimental areas.

The sprinkler system is a modification of the Skinner system of overhead irrigation and consists of two 1-inch pipe lines (fig. 7, *a*) each 54 feet long supported alongside the plot by means of surveyor's tripods (*b*). Each pipe line has a number of holes in perfect alinement into which small nozzles with 1/32-inch orifices are screwed. The number of nozzles determines the intensity of the rainfall applied. With 132 nozzles, storms of 0.06 inch per minute are produced; when every other nozzle is replaced with a plug, the intensity is reduced to 0.03 inch per minute. In order to maintain uniform pressure in the pipe lines, each is provided with three intakes. Pressure regulators and gages (*c*) are provided to maintain the hydrostatic head of each pipe line between 19 and 21 pounds per square inch. To provide ease in transporting, each pipe line can be broken by means of self-alining unions into four sections each a little more than 13 feet long.

The two pipe lines are connected by means of arms and wires (*d*) at their upper extremities to enable one man, stationed at the upper end of one pipe line to control the direction of spray of both lines simultaneously. During a run, the spray is oscillated back and forth across the plot at a slow even rate to provide uniform distribution of the artificial rain. Since the spray is thrown to a height of over 25 feet above the ground surface before it begins to fall, the drops have an impact

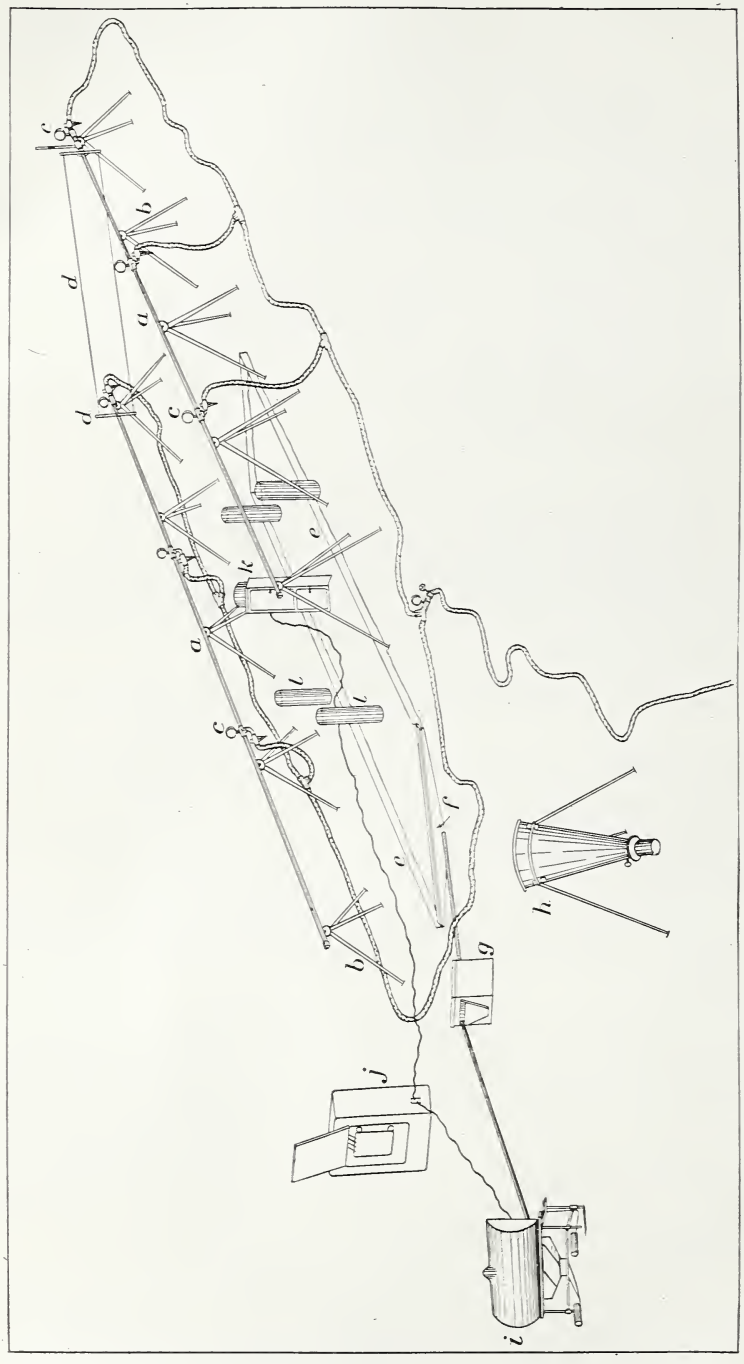

FIGURE 7.—Diagrammatic sketch of the portable erosion-study equipment: *a*, 54-foot, 1-inch pipe line; *b*, surveyor's tripods; *c*, pressure gages and regulators; *d*, oscillator connections; *e*, baffle plates; *f*, collecting trough; *g*, stilling tank; *h*, settling funnel; *i*, run-off gage; *j*, strip-chart recorder; *k*, tipping-bucket rain gage; *l*, standard rain gage.

comparable to natural rain. The artificial storms produced by this system are remarkably realistic and, since their intensity and duration can be closely controlled, are highly satisfactory for study purposes.

The plot, which has projectional dimensions of 6.6 by 33 feet, is delimited on the top and sides by sheet-metal baffle plates set 4 inches into the ground and dovetailed together to make a watertight boundary (*e*). At the bottom of the plot, a trough (*f*) is set to collect the run-off and eroded material and conduct it to a stilling tank (*g*). The trough is sealed to the plot by wetting and packing the soil in a 4-inch strip immediately above the trough (fig. 8). The area of this "artificial erosion pavement," as well as that occupied by rain gages within the plot, are excluded in calculating the plot area.

The stilling tank, or silt trap, is of such a size and is so fitted with baffles that most of the eroded material is caught for subsequent recovery and measurement in the settling funnel (*h*). The quantity which passes through in suspension is determined by testing an aliquot portion of the run-off after it has passed through the run-off gage by a hydrometer calibrated to read ounces of suspended soil per cubic foot. Before a run is started, the silt trap is completely filled with water

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FIGURE 8.—Preparation of the erosion pavement at the foot of plot.

so that the first drop of run-off from the plot replaces water from the silt trap into the run-off gage (*i*). This is a tipping-bucket instrument specially designed for use with this apparatus. It operates on a volumetric rather than the usual gravimetric principle, and is much more accurate than previously used tipping-bucket gages. It is arranged with electrical contacts connected to the strip-chart recorded, (*j*) so that a graphic record of the rate of run-off throughout the run is obtained.

Another pen of the strip-chart recorder is connected to a tipping-bucket rain gage (*k*), similar to those used by the Weather Bureau, located in the center of the plot. This provides a record of the intensity of rainfall applied to the plot. Four standard rain gages (*l*) are located on and near the plot to provide a measure of the artificial storm.

Under ordinary circumstances, two men can set up a complete unit and prepare for a test in about a half day. The sprinkler system must be set up in perfect alinement, the silt trap filled with water, and all electrical connections made and checked to insure satisfactory operation of the rain and run-off gages. When all is in readiness, the pipe lines are turned to direct the spray outside of the plot, the pump started and the pressure adjusted to 20 pounds at the pipe lines. The man who is in charge of the run then signals the oscillator man to roll the pipes in the hangers on the tripods so that the spray will fall on the plot area. At the same

time, he presses a push button to indicate the start of the run on the recorder chart. Distribution of the rainfall across the plot is continued at an even pace by the oscillator man. In this he is guided by his coworker who makes frequent readings of the four standard rain gages. After the run has progressed for the desired length of time, the spray is turned out of the plot, and the pump is stopped. The rain gages and the run-off gage are read, and the eroded material is collected. The contents of the silt trap are transferred to the settling funnel, where the silt collects in the bottom container, and is recovered after the supernatant water has been drained off. After being air-dried, the total eroded material is weighed, and if desired, a sample taken for subsequent laboratory analysis.

After the run-off and erosion from one plot has been thus determined and recorded, the apparatus is moved to an adjacent plot for the next run. Two operators can accomplish this in about 3 hours. Two complete units of the apparatus including pumps and hose can easily be loaded on a 1½-ton stake-body truck and hauled to any area on which runs are to be made.

Because the control of the artificial rainfall is exceedingly difficult during periods of wind, the runs are usually made soon after sunrise, when air movement is at a minimum. In most areas afternoon runs will be made impossible by heavy winds, so that an average of one run a day with each unit is usually maintained. Since very few runs are rendered useless by failure of the apparatus, this permits the accumulation of a great mass of reliable data in a single field season. With an experienced crew of five men operating two units more than 40 successful tests have been made in a single month.

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